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Changing Patterns of Scaffolding and Autonomy During Individual Music Lessons: A Mixed Methods Approach

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Learning implies change. Inside and outside schools, we aim for students to change into people with more skills and knowledge as well as with a growing sense of agency and responsibility. Furthermore, education itself is subject to constant change. In this article, we examine change in 3 case studies in the context of individual music lessons from a complex dynamic systems approach. Three beginning string instrument students and their teacher were followed for 18 months (28 lessons per dyad) by means of video observations. We combine cluster analyses on longitudinal data with qualitative illustrations of moment-to-moment teacher–student transactions to gain insight into how and why change in teaching and learning occurs. The 3 cases show distinct profiles of change: the development of strong suboptimal attractor states, the emergence of optimal attractor states, and a profile that is characterized by falling back into suboptimal attractor states. We discuss how optimal and suboptimal learning and teaching trajectories can unfold over time and how a mixed methods approach can provide valuable new insights for both practice and future research.

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Color versions of one or more figures in the article can be found online at <http://www.tandfonline.com/hlms>.

Learning implies change. Inside and outside schools, we aim for students to change into people with more skills and knowledge but also with a growing sense of agency and responsibility. Furthermore, education itself is subject to constant change. Teachers (not only beginning teachers just entering the profession but also experienced teachers) are expected to continue their professional development, to reflect on their actions, to incorporate new policies and interventions into their teaching, and so on (Tabak & Radinsky, 2015). However, change does not always occur, or it goes in a wrong direction: Effects of educational interventions disappear over the long term, or learning difficulties persist or even intensify over time. An important aim of research in the learning sciences is therefore to investigate why and how change occurs in order to be able to optimize learning and teaching processes. Rarely, however, is the change process *itself* (how and why it occurs) the object of research in this domain. Many studies try to understand learning and teaching by comparing groups of students (or teachers) on different variables at one point in time or comparing pre- and posttests before and after an intervention.

The aim of this study is to provide a theoretical framework that allows us to interpret change in learning and teaching and to illustrate this framework with three case studies in the context of individual instrumental music education. In these case studies, we combine quantitative analyses, which allow us to distinguish between different possible change trajectories over time, with qualitative illustrations, which allow us to zoom in on characteristic moments during lessons and provide insight into *why* change occurs or does not occur.

HOW CAN WE STUDY CHANGE? A THEORETICAL FRAMEWORK

Since its application to social sciences in the early 1990s, a complex dynamic systems approach has been adopted to studying change processes in very diverse domains in the social sciences. More recently, this approach has also been proven to be fruitful in the field of research into learning and teaching (Jörg, Davis, & Nickmans, 2007; Kupers, van Dijk, McPherson, & van Geert, 2014; Steenbeek & van Geert, 2013). A complex dynamic systems approach provides a theoretical framework for examining the learning of children and teachers as processes over time that emerge out of the interaction among many different components (Steenbeek & van Geert, 2013). Learning and teaching are perceived as parts of a complex system. A complex dynamic systems approach to learning and teaching has three main characteristics: (a) Learning is intrinsically social, (b) change occurs on interconnected timescales, and (c) timing is everything.

Learning Is Intrinsically Social

Learning in classrooms, but also in informal contexts and at home, generally occurs through interactions between children and their close social environment

(teachers, parents, peers, etc.). In line with a transactional view of development, this means that child and context shape each other (Sameroff, 2009). That is, not only does the teacher influence the student but also vice versa (Jornet, Roth, & Krange, 2016). Coregulation occurs between teacher and student through their actions and reactions (Fogel, 1993; Steenbeek & Van Geert, 2013). This means that in order to accomplish learning goals, the teacher needs to have not only a set of teaching strategies or general skills but, most important, the ability to read the needs of students from moment to moment and the flexibility to improvise and act on those needs (Lineback, 2015; Tabak & Radinsky, 2015).

Change Occurs on Interconnected Timescales

According to a complex dynamic systems view, change in the here and now of teaching and learning is the basis for change over the long term (Kupers et al., 2014; Steenbeek & van Geert, 2013). However, this connection is bidirectional in the sense that learning and teaching are also dependent on their own (long-term and short-term) history. For instance, the general level of motivation for learning of a student emerges out of moment-to-moment interactions (e.g., experiences of success and competence during the lesson, positive interactions with the teacher and peers), but this general level of motivation of the student constrains the range of possible interactions and experiences during the next lesson. In terms of complex dynamic systems, the general level of motivation serves as a constraint because it restricts the range of microlevel fluctuations (Haken, 2006). Concluding, learning, and teaching occur on nested, interconnected timescales (Derry et al., 2010; Kupers et al., 2014).

Timing Is Everything

Over time, systems develop certain attractor states, which can be described as states that the system is drawn toward (Howe & Lewis, 2005). For instance, consider a problematic learning situation in which a student procrastinates on work during the lesson and shows a lot of off-task behavior, which annoys the teacher, who then prefers to help more motivated students, which causes the student's off-task behavior to persist, and so on. Here neither the student nor the teacher is primarily at fault, but rather they find themselves caught in a pattern that can be difficult to break out of. Attractor states can be stronger or weaker depending on the intraindividual variability that characterizes the system. From earlier research, we know that the amount of intraindividual variability in, for instance, parent-child or teacher-student interactions can be a predictor of how susceptible a system is to change (van Dijk & van Geert, 2015). In general, systems with (temporary) high intraindividual variability are more likely to change. Studies on children's learning in mathematics show that right before children discover a new, more sophisticated strategy of problem solving, there is

a temporal increase in the session-to-session variability of their performance (Siegler & Svetina, 2002). Translated to education, we expect that change (for instance primed by an educational intervention) is more likely to occur if the system shows a heightened level of variability prior to the start of the intervention. For instance, it is a well-known fact that children's social networks are likely to change when children make the transition from primary to middle school, as children need to renegotiate their position in the group (Espelage & Swearer, 2003). Therefore, it would make sense to implement an intervention aimed at preventing bullying at this time of transition, when the social system is already flexible.

STUDY CHANGE IN WHAT? TWO RELEVANT DIMENSIONS

Autonomy

Developmental and educational theorists consider movement toward greater autonomy and self-initiation to be the hallmark of healthy development (Ryan, Deci, & Grolnick, 1995). Learning itself can be seen as an autonomous act: From birth onward, human beings can be characterized as proactive learners who tend to participate autonomously in activities that provide novelty and challenge.

The environment plays an important role in children's autonomy development. In educational settings, teachers' behaviors can either foster or hinder the autonomy development of their students (see Kupers, van Dijk, van Geert, & McPherson, 2015; Reeve & Jang, 2006; Reeve, Jang, Carrell, Jeon, & Barch, 2004). Research shows that on average an autonomy-supportive teaching style is linked to a range of positive student outcomes, such as intrinsic motivation and engagement (see Stroet, Opdenakker, & Minnaert, 2013, for an overview). In addition, autonomy-supportive teaching is related to students' sense of autonomy (Reeve & Jang, 2006; Reeve, Nix, & Hamm, 2003) as well as their autonomous behavior during learning (Plimpton & DeCharms, 1976).

A large part of the literature on student autonomy takes teaching style (autonomy supportive or controlling) as the independent variable and measures its effect on student autonomy. This is based on the assumption that the teacher is the locus of control who determines (albeit indirectly) the student's level of autonomy. An alternative perspective based on the complex dynamic systems approach is that motivation and self-determination in particular—and learning in general—can be seen as bidirectional, dynamic processes in which student and teacher mutually influence each other. These teacher–student interactions, rather than (or complementary to) individual behaviors, are taken as the unit of analysis (Granott, 1998; Kupers, van Dijk, van Geert, & McPherson, 2015; Meyer & Turner, 2002; Steenbeek, Jansen, & van Geert, 2012; Turner & Patrick, 2008).

Scaffolding

An important way in which teachers can aid students' learning is by scaffolding, which is providing temporary support when a student is learning a task he or she has not quite mastered yet. After the task is completed, the support can be gradually toned down (Granott, Fischer, & Parziale, 2002; Wood, Bruner, & Ross, 1976). Scaffolding has several important aspects. First, scaffolding implies a coupling between the performance level of the student and the level of teaching content of the teacher (van Geert & Steenbeek, 2005). There is an optimal distance between the two when the level of the teacher always stays slightly ahead of the current level of the student. This optimal distance is not fixed but instead can vary among students and can change over time. The continuous adaptation of the teacher's level to the student's current level is called *contingency* and is a core characteristic of scaffolding (van de Pol, Volman, & Beishuizen, 2009, 2010). This also implies that scaffolding cannot be planned in advance but instead develops in the lesson itself depending on the teacher's and student's previous actions. A second characteristic of scaffolding is that the teacher's support fades out over time and, connected to this, responsibility for the task is transferred from teacher to student. This process is cyclical; after one subgoal of the task is accomplished, the process of scaffolding starts again for the next subgoal in the task (Kupers, van Dijk, & van Geert, 2015). The third characteristic aspect of scaffolding is the relation between timescales: Long-term outcomes (such as student learning over longer periods of time) emerge out of repeated scaffolding interactions in the here and now (real time). For instance, if scaffolding is effective, we assume that real-time interactions between teacher and student that are characterized by high levels of contingency will be associated with better learning outcomes over the long term.

These two dimensions (autonomy and scaffolding) are connected through the central notion of *agency*: Students are seen as active participants in their own learning and development. The ultimate goal of scaffolding is autonomous competence; as the teacher's support is faded out, the responsibility for learning is transferred from teacher to student. Similarly, Meyer and Turner (2002) described different ways in which contingent scaffolding can foster students' self-regulation; one important way is by fostering students' autonomy as learners. Agency is typically negotiated through teacher–student interactions (González & DeJarnette, 2015; Rainio, 2008). For instance, teachers' preferences for different moves during interactions are shown to both be related to the general characteristics of the students in their classes and equally depend on the perceived, moment-to-moment needs of those students (González & DeJarnette, 2015).

The interactional nature of agency is studied through different research traditions. On the one hand, there is a tradition of qualitative research that zooms in on key moments during the lesson in which agency is negotiated, fostered, or

diminished (Meyer & Turner, 2002; Rainio, 2008). On the other hand, most research based on the complex dynamic systems paradigm quantifies these data (by analyzing the occurrence of patterns in teacher–student interactions) in order to be able to zoom out and look at more global changes over time (Martin & Sherin, 2013). An illustration of this latter approach is a study by Steenbeek et al. (2012) in which characteristics of moment-to-moment teacher–student interactions, in this case matches and mismatches in teacher and student actions and reactions, were linked to the emergence of problematic learning trajectories over a longer period of time (in this case 2 years). We see both approaches as complementary and together able to shed light on both *how* and *why* change occurs.

WHERE CAN WE STUDY CHANGE? THE CONTEXT OF INDIVIDUAL MUSIC LESSONS

Music is often, in some shape or form, an important aspect of children’s lives. In addition to music being part of most primary and secondary school curriculums, many children take lessons to learn to play a musical instrument (in the Netherlands, for instance, 35% of children are involved in music or singing, of whom about 40% take lessons; Van den Broek, De Haan, & Huysmans, 2009). These often individual lessons are highly suitable contexts for studying change in teacher–student interactions and more specifically for studying patterns in scaffolding and the coregulation of student autonomy for several reasons. The first reason is that learning to play a musical instrument requires a complex set of skills that take years to develop. This makes music education a very suitable context for studying change in student–teacher interactions over longer periods of time. The second reason is that music lessons outside of school are often a voluntary activity, and, given the difficulties that are part of the beginning stages of learning to play an instrument, maintaining intrinsic motivation is especially relevant in this context. Because of these characteristics, music lessons can provide interesting cases for studying change in teacher–student interactions both on the microlevel and on the macrolevel.

One-to-one music lessons, in which students learn to play a musical instrument in a classical master–apprentice relationship, have a long history. On the one hand, the intensive individual attention that is characteristic of individual instrumental music lessons provides the opportunity to carefully scaffold the student’s learning process and to build a long-lasting relationship with the teacher (Gaunt, 2010). On the other hand, this tradition can result in a heavily skewed power distribution, which can greatly undermine the student’s autonomy and motivation (McPherson, Evans, Kupers, & Renwick, 2016; Persson, 1994). Indeed, contemporary empirical investigations of teacher–student interactions in individual music lessons confirm

that teachers can be very directive and insufficiently sensitive to responding to students' needs (Gaunt, 2010; West & Rostvall, 2003).

Teaching Style and Method as Constraints

Earlier in the introduction (in the Timing Is Everything section), we explained the role of constraints in complex dynamic systems. As explained there, constraints are higher order variables that restrict the range of moment-to-moment interactions. In the context of individual music lessons, we highlight two important constraints: teaching style and method. Over the years, teachers develop their own personal *style of teaching* based on their interactions with many different students in their lessons and also based on their own prior experiences with their own teachers. In turn, this style of teaching influences what happens in each lesson. This does not mean that teachers do the same things in every lesson but rather that some types of teacher–student interactions are more likely to occur than others, given a certain style of teaching. Creech (2012), for instance, distinguished between different types of teacher–student interactions during individual string instrument lessons and hypothesized that a too rigid, directive teaching style can serve as a constraint to the flexibility in teacher–student interactions and long-term outcomes.

Another possible constraint is the *method* that teachers use. Whereas some music teachers do not rely on one specific method but instead are more eclectic, other music teachers use a method such as Kodály, Orff, or Suzuki. All of the music teachers in our study were trained as Suzuki teachers. The Suzuki method is an internationally recognized method of instrumental teaching (developed originally for string instruments) that allows children to start learning to play an instrument from a young age. There is an emphasis on aural development, with the student learning to play from hearing before learning to play from sheet music and learning in small steps through repetition. Besides individual lessons (which were studied here), students also take part in group lessons (Suzuki, 1969). The Suzuki method is based on a philosophy of teaching that emphasizes the early and positive stimulation of natural abilities in children (each child can learn to play the violin just like all children learn to speak their native language), with a significant role for parents and teachers (Hendricks, 2011; Suzuki, 1969).

Some authors fear that teachers rely too much on a certain method, which can lead to little room for spontaneous emergence and flexibility in moment-to-moment interactions (Juntunen & Westerlund, 2011; Regelski, 2002). However, as Hendricks (2011) argued, this can be avoided by regular, systematic reflection aimed at self-improvement (which also happens to be quite central to the philosophy of Suzuki). In this way, a teaching method can be adapted to the needs of the student and teacher as they unfold from moment to moment and can therefore contribute to long-term growth rather than hindering it.

RESEARCH QUESTIONS

In the current article, we combine quantitative analyses on the structure of longitudinal data on teacher–student interactions with qualitative illustrations of key moments in the microlevel interactions between music teacher and student. By combining the strength of both qualitative and quantitative approaches, we hope to increase our understanding of change in teaching and learning processes in this specific context while at the same time discussing more fundamental change mechanisms that also play a role in other contexts.

The multiple-case study is guided by the following research questions:

1. How do teacher–student interactions in the three cases change over longer periods of time (18 months)?
2. What moment-to-moment interactions are most characteristic of the three dyads, and how do they link to long-term change?

METHOD

Research Participants

Two violin teachers and one cello teacher participated in this study together with three of their beginning students. The students were between 5;3 and 5;11 years old at the start of data collection and had been involved in music lessons for 10 months on average. The students came from higher socioeconomic backgrounds and lived in different parts of The Netherlands. Two of the three teachers were teaching in a private studio, and one teacher worked in a public music school. All teachers had more than 20 years of teaching experience and had followed several years of Suzuki teacher training after completing the conservatorium. One of the teachers also trained new Suzuki teachers herself.

The dyads were chosen from a larger sample of eight dyads based on their scores for autonomy. At the end of data collection, teachers rated students' general need for autonomy on a 5-point Likert scale ("In general, this student wants to take initiative during the lesson," with answers ranging from 1 = *never* to 5 = *very often*). From these eight dyads, we selected the three dyads with the most extreme scores for general need for autonomy: two students with a low need for autonomy and one with a high need for autonomy. This enabled us to contrast trajectories associated with different overall student characteristics in order to link macrolevel change (overall need for autonomy) to possible differences in moment-to-moment interactions. An overview of the three students is given in [Table 1](#). Before the start of the study, the teachers and parents of the

TABLE 1
Student Characteristics

Name ^a	Thijs	Robin	Milou
Age	5;3	5;3	5;11
Instrument	Cello	Violin	Violin
Months of lessons	16	8	8
Need for autonomy	5	1	2
Progress	5	4	5

^aStudents' names were changed for the sake of privacy.

TABLE 2
Overview of All Variables

Main Category	Variable	Measurement Level (Scale)	No. of Measurement Points per Dyad
Autonomy	Student autonomy	Micro (−1 to 1) (All instances of autonomy = 1 are labeled as resistance or engagement)	28 (1 per lesson)
	Teacher autonomy support	Micro (−1 to 1)	28 (1 per lesson)
	Out-of-synch	Micro (> 0; frequency)	28 (1 per lesson)
	General student autonomy	Macro (1–5)	1
Scaffolding	Contingency	Micro (0–1)	28 (1 per lesson)
	Dispersion	Micro (0–1)	28 (1 per lesson)

children signed an informed consent form. All procedures were approved by the Ethical Committee Psychology of the University of Groningen.

Measurement

The quantitative variables were coded with a coding scheme based on the literature on autonomy regulation and scaffolding. See [Table 2](#) for an overview of all quantitative variables.

Autonomy variables were coded for all verbal utterances of the teacher and student (in the first 10 min of each lesson). We measured teacher autonomy support by rating all utterances of the teacher on a scale from −1 to 1, with −1 being the most autonomy diminishing and 1 being the most autonomy supportive. The scale was based on the literature on autonomy-supportive teaching (Reeve & Jang, 2006) as well as on measures for teacher openness in teacher–student interactions (Meindertsma, van Dijk, Steenbeek, & van Geert, 2014). The

core of this measure is how much room teachers left for student initiative or how much teachers encouraged student autonomy at any point in the lesson. For instance, when the teacher explicitly disapproved of a student initiative (“I don’t think that is a good idea”), this was rated as -1 . A directive instruction is a bit less autonomy diminishing, but still does not leave much room for student initiative and was therefore rated as -0.6 . Providing feedback (which can be positive or negative), giving information, and asking (informative) questions are already more autonomy supportive, because the student has room to figure out the correct solution himself or herself. Emotional scaffolding (rated as $.6$) refers to comments of the teacher relating directly to the student’s motivation (for instance, expressing understanding when the student finds something difficult), and explicit autonomy-supportive expressions occur when the teacher offers the student a meaningful choice or responds positively to a student’s initiative. The complete scale of teacher autonomy support is shown in Figure 1 (see also Kupers, van Dijk, van Geert, & McPherson, 2015).

Student autonomy expression was rated as negative (-1), neutral (0), or positive (1). The values 0 and 1 were coded for each student utterance. A value of -1 was assigned when the student did not respond to a question by the teacher (note that a nonverbal response, such as playing after the teacher asked, “Can you play this part for me?”, also counted as a response). A positive value was assigned when the student took initiative in the lesson, for instance by asking a question or bringing in a new idea. Positive autonomy expressions (value = 1) can either be *engaged* (when the student is on task, e.g., asking a question about the task) or *resistant* (when the student is off task, e.g., saying, “I don’t want to do this anymore” or bringing up an unrelated topic in the conversation). Student autonomy was neutral (value = 0) when the student said something that did not involve taking initiative (e.g., answering a question).

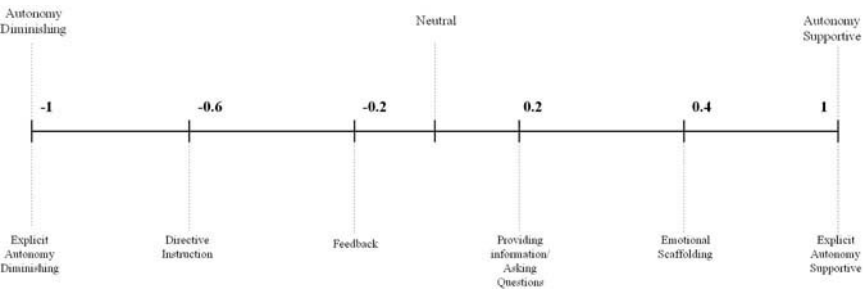


FIGURE 1 Scale of teacher autonomy support, ranging from autonomy diminishing (-1) to autonomy supportive (1).

Scaffolding variables were coded for each assignment that was addressed in the lesson. Each assignment that the teacher gave during the lesson was rated on its complexity in relation to the previous assignment: more complex (forward), less complex (backward), same level (repeat), or unrelated to the previous assignment (new task). Consequently, each attempt to execute this assignment was coded. The student codes represent the level of that student performance of the task at hand (correct, partially correct, or incorrect). Note that the code for the level of the student's performance depended on what exactly the task was. For instance, when the teacher said, "Try to make a difference between loud and soft notes," we took only this difference in dynamics into account when judging the student's performance (and not, for instance, whether the student played in tune). Neither the teacher assignments nor the student responses were exclusively verbal; for instance, when the teacher played a fragment and the student was expected to repeat that fragment, this was also labeled an assignment. The teacher and student levels over time in each lesson were plotted in a state space grid (SSG; Lamey, Hollenstein, Lewis, & Granic, 2004; see Figure 2a and 2b), resulting in 28 SSGs per dyad. A state space consists of all possible interaction states of the teacher–student dyad. Each coded lesson is represented as a series of dots in the state space; each dot represents one sequence of teacher–student behavior (a dot in the bottom left cell, for instance, means that the student has performed an assignment correctly, after which the teacher presents a new assignment). On the basis of the literature on scaffolding, we determined which combinations of actions could be labeled *contingent scaffolding*. The criteria were that the teacher stayed ahead of the student but not so much that the student could not keep up (e.g.,

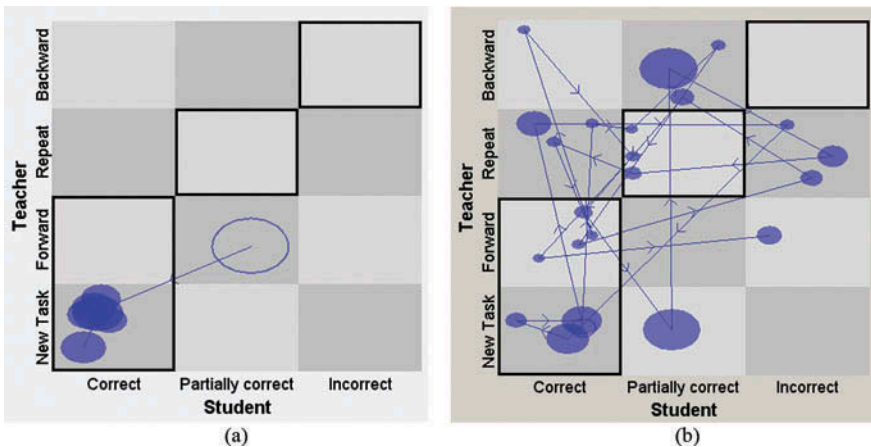


FIGURE 2 Example of state space grids of lessons with (a) low dispersion and (b) high dispersion. The states with a black line represent contingent scaffolding.

increasing complexity or starting a new task after a correct performance, decreasing complexity after an incorrect performance, and staying on the same level after a partially correct performance). The contingent sequences of teacher responses to student task executions are the cells marked with a black line in Figure 2a and 2b. SSGs can be used not only to analyze proximal sequences of events but also to measure the overall temporal structure of the dyadic interaction within each lesson (Dishion, Nelson, Winter, & Bluuock, 2004) and thus can be used to characterize the teacher–student interactions in terms of intraindividual variability or flexibility.

Besides the variables representing student and teacher behaviors, described previously, we also calculated variables that represented different aspects of dynamics of the teacher–student variables within each lesson.

Out-of-synch was calculated from the real-time difference between the student's level of autonomy expression and the concurrent teacher level of autonomy support. Out-of-synch is the duration per lesson (in half seconds) of differences in autonomy levels greater than 1. For instance, when the student takes initiative (value student autonomy = 1) and the teacher responds negatively (value teacher autonomy support = -1), this is a moment of out-of-synch.

Contingency is the proportion of contingent actions relative to all actions per lesson.

Dispersion was calculated from the same SSGs as contingency. Dispersion indicates to what extent the interaction shows high (all interactions distributed evenly across the state space) or low (all interactions concentrated in one or a few cells) levels of intraindividual variability. Each lesson has a value between 0 and 1: 0 if all of the interactions are located in one cell, and 1 if the interactions are evenly spread out over all cells (Hollenstein, 2012). In Figure 2a and 2b we see two examples of interactions with varying levels of dispersion. In Figure 2a, all but one interaction fall into the same cell (correct → new task → correct → new task → correct, etc.). This is a highly predictable sequence, and therefore this lesson has a low value for dispersion. One could also remark that the correct–new task state is a strong attractor in this lesson. In Figure 2b, the interactions are much more variable: The nodes in the SSG are distributed quite evenly across most cells. Therefore, this lesson has a high value for dispersion. This means that there are no strong attractors in this lesson.

Procedure

Because this study focused on change in interactional patterns over time, a design with dense repeated measurements (both within lessons and over longer periods of time) was used. The data collection for this longitudinal study spanned 18 months and consisted of seven waves of data collection that were 3 months apart. During each wave, four consecutive weekly music lessons were videotaped, resulting in 28 repeated measurements per dyad. Either the first author or the music teachers themselves recorded the videos with a simple video camera on a tripod. The teachers were told to conduct their lessons as they normally would.

The recorded lessons usually lasted either 15 or 30 min. For every recorded lesson, the first 10 min (starting from the point when the teacher formulated the first assignment) were coded on the basis of a detailed coding scheme using professional coding software (The Observer Version 10.5, Noldus, Wageningen, the Netherlands). An overview of all variables can be found in Table 2. We assessed interobserver reliability by comparing the codes of the first author with those of three independent, trained observers. For the autonomy variables (teacher autonomy support and student autonomy expression), reliability calculations resulted in Cohen's kappas of .84 for student autonomy expression (agreement ranged from 64% to 100% per video), .96 for the variable teacher autonomy support (86%–99% agreement per video), and .79 for the subcategories of teacher autonomy support (72%–89% agreement), which is a substantial level of agreement. Interobserver reliability for the scaffolding variables (teacher assignment level and student performance level) was determined between two observers, resulting in Cohen's kappas of .91 for the teacher level (agreement between 67% and 100%) and .78 for the student level (agreement between 63% and 95%).

Analyses

We used a combination of quantitative analyses and qualitative illustrations in order to be able to (a) characterize long-term change in the three dyads (quantitatively) and (b) zoom in on characteristic moment-to-moment interactions that played a role in these change processes (qualitatively).

Quantitative Analyses

The data of the dyads were plotted over time. For each dyad, we tested whether the autonomy and scaffolding variables showed a global increase or decrease over time with nonparametric tests. In order to do this, we performed Monte Carlo simulations, in which the linear slope of the empirical observations is tested against the slope of randomly shuffled data. In addition, in order to get a full picture of teacher–student interactions over longer periods of time, we performed cluster analyses, which allowed us to look for types of teacher–student interactions in terms of autonomy and scaffolding and see how these interactions changed over time. We conducted these cluster analyses in two steps. First we smoothed the data for each dyad. Smoothing is a technique for reducing the local variability while maintaining information about local trends in the data. By reducing the local variability, one can make the time-dependent and eventually changing relationships between variables more salient, that is to say, easier to capture visually. We used the loess (locally weighted regression) smoothing technique, which calculates weighted regression lines in windows of data. (When the window is 10 data points, for instance, the first point in the curve comes from regression through data point 1 to 10, the second on 2 to 11, etc. In the calculation of the regression

parameters, the middle value of the window has the greatest weight and the values toward the beginning and end of the window are given decreasing weights.) We used these smoothed and normalized data as input for the cluster analyses. Normalization was used because all variables were measured on different scales; putting them on the same scale allowed us to link the increases and decreases in the variables to one another. Subsequently we performed a hierarchical cluster analysis on the smoothed data with the aid of Tanagra software. This was done to determine whether there were meaningful groups of measurement points for each dyad based on the shared characteristics of these measurement points. Hierarchical cluster analysis provides test values¹ of each variable for each cluster. These test values indicate which variables are most characteristic of the particular clusters, with relatively high (>1) or relatively low (<-1) values indicating the most characteristic variables.

Qualitative Illustrations

We used the cluster analyses as a basis for zooming in on the most characteristic patterns of interactions for each dyad, which helped us to understand not only how but also why change occurs. For each dyad, we chose two lessons from two predominant clusters. We chose the lessons most characteristic of that cluster (so, for instance, if a cluster of lessons was characterized by low student autonomy and low teacher autonomy support, we chose the lessons with the most extreme average values for those variables). In the same way, we chose the excerpt from this selected lesson to be most characteristic of that lesson (in our example, we would look for moments in the interaction characterized by low student autonomy and low teacher autonomy support). In this way, we gained insight in the micro-level interactions that drove long-term change.

RESULTS

How Do Teacher–Student Interactions in the Three Cases Change Over the Course of 18 Months (Quantitative)?

Teacher and Student Behaviors/Indicators

Students' Autonomy Expressions. All three students' autonomy expressions over time are depicted in Figure 3. The two students who were identified as having a general low need for autonomy by their teachers (Milou and Robin; the dotted lines in Figure 3) show few positive autonomy expressions during the first

¹The test values are provided in the descriptive output of the cluster analyses in Tanagra. The following link to the Tanagra tutorial provides information on the calculation of the test values: <http://data-mining-tutorials.blogspot.nl/2009/05/understanding-test-value-criterion.html>.

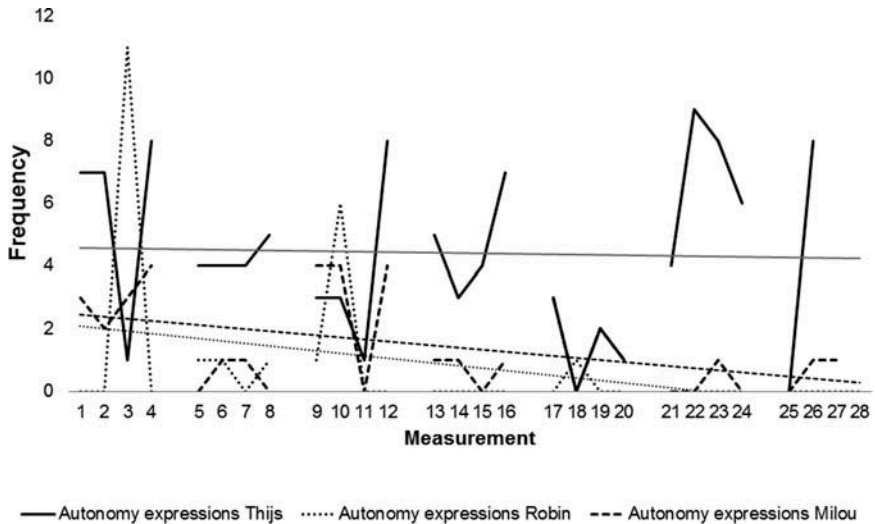


FIGURE 3 Frequency of autonomy expressions per lesson for Thijs (high-autonomy student) and Robin and Milou (low-autonomy students).

couple of measurements that decrease even further over time until they show no autonomy expressions at all in later lessons. The student with an identified high need for autonomy (Thijs; the solid line in Figure 3) shows highly variable levels of autonomy expression over time but no clear increase or decrease. The students with an identified low need for autonomy hardly ever show resistance.

Teachers' Autonomy Support. Figure 4 shows levels of teacher autonomy support over time for the three teachers. In general, the teachers show varied levels of autonomy support. The teacher of Thijs was generally the most autonomy supportive, whereas the teacher of Milou was most controlling. We see that over time the teacher of Thijs seems to slightly increase her autonomy support (nonsignificant increase; $p = .1$), whereas the teacher of Milou becomes more controlling ($p = .001$). The autonomy support levels of the teacher of Robin do not show a linear increase or decrease.

Out-of-Synch. Out-of-synch moments are depicted in Figure 5. Remember that out-of-synch represents the amount of time in which there is a large difference between the level of student autonomy expression and teacher autonomy support. This can occur when the teacher is highly controlling and the student is expressing high autonomy and also when the student expresses low levels of autonomy while the teacher is very autonomy supportive. The level of

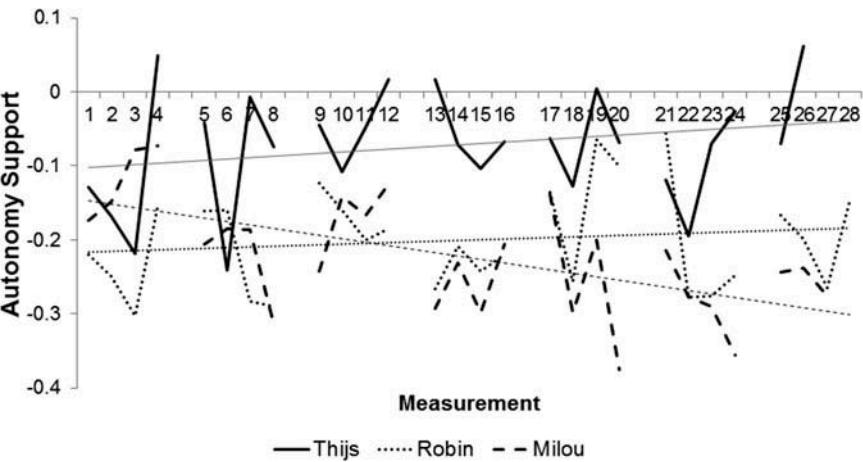


FIGURE 4 Average level of teacher autonomy support per lesson over time for Thijs (high-autonomy student) and Robin and Milou (low-autonomy students).

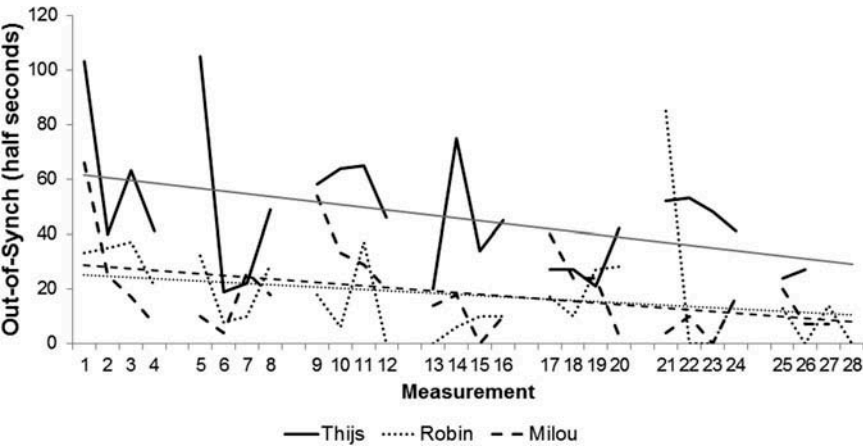


FIGURE 5 Out-of-synch moments (in half seconds) per lesson over time for Thijs (high-autonomy student) and Robin and Milou (low-autonomy students).

out-of-synch decreases over time for all three dyads (Thijs, $p = .02$; Robin, $p = .002$ [without outlier at Point 27; $p = .10$ with outlier]; Milou, $p = .02$).

Scaffolding Contingency. The levels of contingency per lesson varies around 50% of the interactions (see Figure 6). There seems to be a very slight

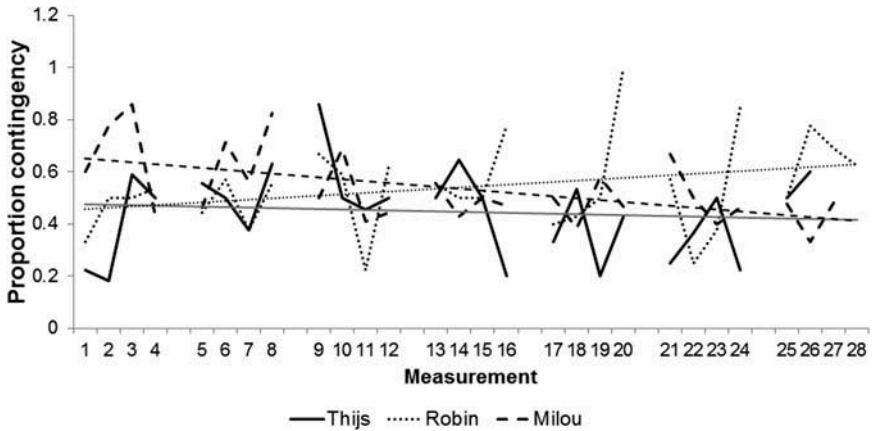


FIGURE 6 Levels of contingency per lesson over time for Thijs (high-autonomy student) and Robin and Milou (low-autonomy students).

general increase in contingency (combined with higher lesson-to-lesson variability) in Robin's lessons (slope = .006, $p = .06$) and a decrease in contingent scaffolding for Milou's lessons (slope = .009, $p = .02$). For Thijs's lessons, contingency levels are variable, with no clear increase or decrease.

Scaffolding Dispersion. Figure 7 shows the dispersion in scaffolding states (i.e., the within-lesson variability in scaffolding states). As a reminder, a value of 0 indicates a very stable interaction (all behavior occurs in one cell of the SSG) and a value of 1 indicates a highly variable interaction (behaviors are evenly distributed among all cells of the SSG). The dispersion in the scaffolding states is and stays very high (around .85 on a scale from 0 to 1), with no clear increases or decreases over time for any of the three dyads, with the exception of two local drops in dispersion for Milou and Thijs. This means that overall the scaffolding interactions throughout these 18 months are relatively variable.

Cluster Analyses

In order to look at profiles of change for the three dyads, we performed cluster analyses on all variables together and plotted the data over time. In Tables 3, 4, and 5, the test values for all variables for each of the dyads can be found. In Figures 8, 9, and 10, the normalized, loess-smoothed variables are plotted over time for each dyad. The clusters are represented in the gray blocks in the figures in order to illustrate how the types of teacher–student interactions change over time. So, for instance, the teacher–student interactions in the first six lessons of Milou can be described as opportunity providing

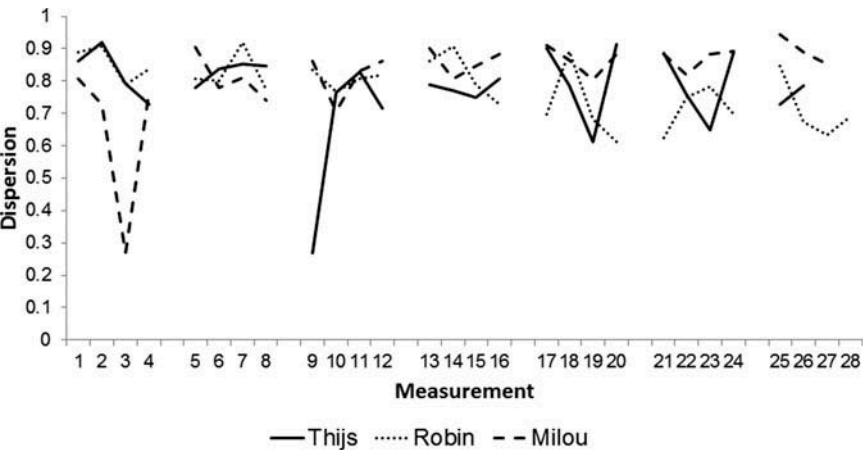


FIGURE 7 Levels of dispersion (variability in the state space) per lesson over time for Thijs (high-autonomy student) and Robin and Milou (low-autonomy students).

TABLE 3
Descriptions of Hierarchical Cluster Analysis Clusters: Thijs

Cluster 1: Conflict 4 Data Points (15.4%)		Cluster 2: Flow 13 Data Points (50%)		Cluster 3: Teacher Led 9 Data Points (34.6%)	
Variable	Test Value	Variable	Test Value	Variable	Test Value
Out-of-synch	3.82	Contingency	4.29	Dispersion	1.08
Dispersion	3.01	Engagement	3	Resistance	0.48
Resistance	2.53	Autonomy support	2.87	Autonomy support	−0.35
Engagement	0.24	Out-of-synch	−0.21	Out-of-synch	−2.68
Contingency	−2.15	Resistance	−2.29	Contingency	−2.88
Autonomy support	−3.52	Dispersion	−3.2	Engagement	−3.34

(Cluster 1), those in the next six lessons as student led (Cluster 2), and those in the final 16 lessons as teacher led (Cluster 3; see Figure 8).

Milou: A Strong Suboptimal Attractor State. Figure 8 displays the trends for the variables over time.

In the first four lessons (opportunity providing), the teacher is providing high levels of autonomy support and contingent scaffolding, but the student is showing high levels of resistance. The second cluster (student led) consists of lessons (7–12) in which the student is showing relatively high levels of engagement and

TABLE 4
Descriptions of Hierarchical Cluster Analysis Clusters: Robin

Cluster 1: Conflict 5 Data Points (17.9%)		Cluster 2: Exploring 13 Data Points (46.4%)		Cluster 3: Autonomy Building 5 Data Points (17.9%)		Cluster 4: Skill Building 5 Data Points (17.9%)	
Variable	Test Value	Variable	Test Value	Variable	Test Value	Variable	Test Value
Resistance	4.66	Dispersion	2.15	Autonomy support	4.23	Contingency	3.84
Engagement	3.65	Engagement	0.2	Out-of-synch	2.31	Autonomy support	-0.51
Out-of-synch	3.08	Autonomy support	-1.02	Contingency	0.98	Resistance	-1.43
Dispersion	2.88	Contingency	-1.33	Resistance	-1.43	Engagement	-2.15
Autonomy support	-2.4	Resistance	-1.38	Engagement	-1.76	Out-of-synch	-2.7
Contingency	-3.08	Out-of-synch	-2.07	Dispersion	-2.79	Dispersion	-2.88

TABLE 5
Descriptions of Hierarchical Cluster Analysis Clusters: Milou

Cluster 1: Opportunity Providing 6 Data Points (21.4%)		Cluster 2: Student Led 6 Data Points (21.4%)		Cluster 3: Teacher Led 16 Data Points (57.1%)	
Variable	Test Value	Variable	Test Value	Variable	Test Value
Resistance	4.98	Engagement	3	Dispersion	4.12
Autonomy support	4.08	Out-of-synch	2.48	Resistance	-3.09
Contingency	3.85	Contingency	1.39	Engagement	-3.69
Out-of-synch	2.13	Autonomy support	0.99	Out-of-synch	-3.82
Engagement	1.45	Dispersion	-0.5	Autonomy support	-4.2
Dispersion	-4.47	Resistance	-1.26	Contingency	-4.35

the interactions have moderate to high levels of out-of-synch and scaffolding contingency. This is followed by a final cluster that comprises most lessons (13–27) and can be characterized as teacher led; the teacher is very directive, the student is showing low levels of autonomy, and there is little contingent scaffolding.

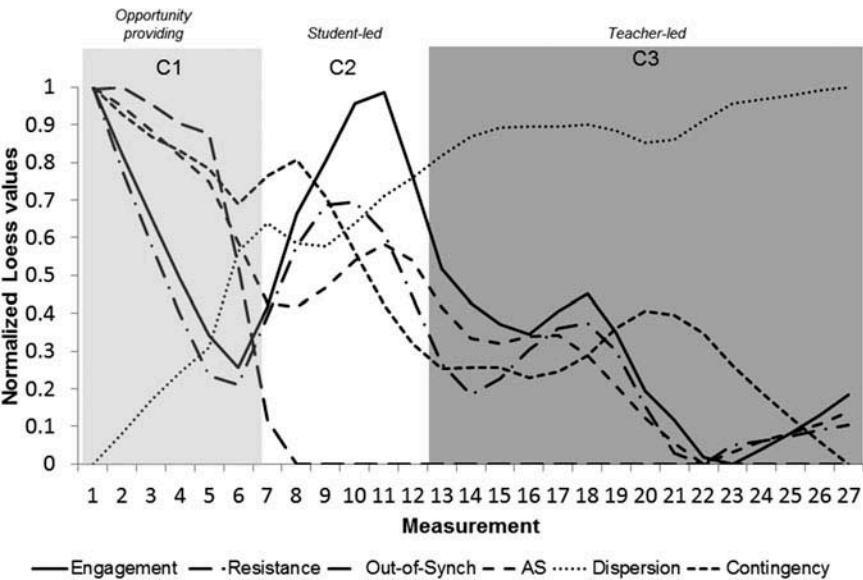


FIGURE 8 Hierarchical cluster analysis clusters of measurement points over time for Milou, combined with loess curves for all six variables. C1 = Cluster 1; C2 = Cluster 2; C3 = Cluster 3; AS = autonomy support.

Robin: Falling Back Into Suboptimal (Autonomy) Attractor States. In the data of Robin, four main clusters of measurement points can be distinguished that are depicted over time in Figure 9.

The first lessons (1–4) of Robin are marked by conflict (relatively high resistance but also engagement, low autonomy support, and low contingency). The teacher–student dyad then moves on to a prolonged phase of exploring (high variability in the scaffolding states combined with values of the other variables that vary around the mean; note also the variability within this cluster as shown in Figure 10). Lessons 18 to 22 fall into the third cluster, in which interactions are characterized by autonomy building. The final cluster of lessons (which we call *skill building*) shows high levels of contingency but low levels of the other variables (except average values for autonomy support). After a short period of trying to support the student’s autonomy, the dyad is focusing on learning but less on autonomy development.

Thijs: The Emergence of Positive Attractor States. The cluster analysis on Thijs’s data yielded four main clusters of measurement points. These are depicted over time in Figure 10.

Cluster 1, which includes the first four measurement points, is characterized by high levels of out-of-synch, high dispersion, high resistance, and low autonomy

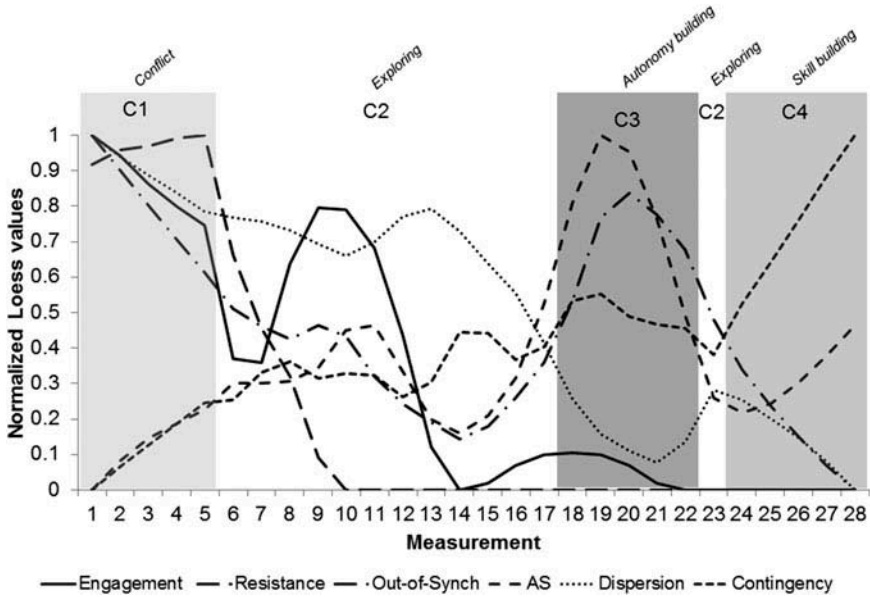


FIGURE 9 Hierarchical cluster analysis clusters of measurement points over time for Robin, combined with loess curves for all six variables. C1 = Cluster 1; C2 = Cluster 2; C3 = Cluster 3; C4 = Cluster 4; AS = autonomy support.

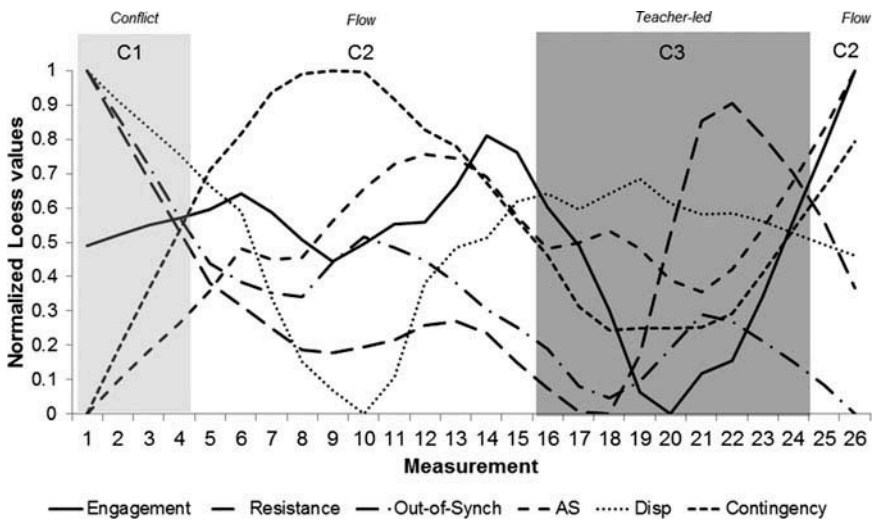


FIGURE 10 Hierarchical cluster analysis clusters of measurement points over time for Thijs, combined with loess curves for all six variables. C1 = Cluster 1; C2 = Cluster 2; C3 = Cluster 3; AS = autonomy support.

support. In general we could call this a cluster marked by conflict (similar to the first lessons of Robin): The teacher and student were not well adapted in terms of autonomy, with the teacher trying to control the student and the student actively resisting. In addition, the scaffolding interactions were relatively disordered and not contingent. The following measurement points fall into the second cluster, which comprises most measurement points and which reappears at the end of the time series. This second cluster is characterized by high contingency, high autonomy support, high engagement, and low dispersion. These interactions seem to be characterized by flow: The student is highly autonomous in a positive way (on task), and the teacher supports this student engagement. At the same time, scaffolding is contingent and the interactions are relatively ordered. This second cluster alternates with a third cluster, which appears from the middle to the near end of the time series. The third cluster is marked by low levels of student autonomy (especially low engagement), relatively few moments of out-of-synch, and lower levels of contingency. We could call this the *teacher-led* cluster: The student is less involved compared to the previous clusters and the scaffolding is less contingent. After some lessons characterized by more passive interactions, the positive flow state reappears.

Which Moment-to-Moment Interactions Are Most Characteristic of the Three Dyads, and How Do They Link to Long-Term Change? (Qualitative)

Milou: A Strong Suboptimal Attractor State

As explained in the Analyses section, the goal of the following illustrations is to characterize the types of lessons (yielded from the quantitative analyses) by means of moment-to-moment interactions. The following excerpt comes from a lesson from the student-led cluster (Lessons 7–12) in which the student shows relatively high levels of autonomous engagement. In this part of the lesson, the teacher and student play a short piece together from sheet music. On the score, several sections of the piece are marked A, B, C, and so on.

Excerpt 1. Teacher–Student Interaction in Student-Led Cluster (Milou)

[After playing a piece or two voices together, student gets lost halfway]

Teacher (T): Yes, until here. Could it be that you've waited somewhere? Here?

Student (S): [Silent]

T: Let's start at B.

S: [Silent; does not respond]

T: This is B [points] and then you start there. On the G string.

S: Where do I start?

T: We start here, that's a G but there's also a letter, do you see?

S: Nods.

- T: Here's a character A [points]. So if you want to start halfway the piece, then sometimes you can say we start at B. At the character B. And that's there.
- S: Character B there?

During this interaction, the student asks clarifying questions (thereby showing engagement). The teacher responds by answering her questions and briefly explaining the meaning of the characters on the sheet music before they continue. However, the teacher's level of autonomy support is still quite low because it is the teacher who determines what happens and in which way. Note that although the teacher-student interactions are relatively more student led compared to the other lessons, in absolute terms the student shows little initiative and the teacher is clearly the one who has the biggest influence on how the lesson is unfolding.

After a number of lessons with interactions that are (relatively) student led, the interactions become more and more teacher led: Student engagement and resistance decline, and the teacher becomes less and less autonomy supportive. These types of interactions continue for the remainder of the 18 months of data collection, which qualifies them as a strong attractor state for this dyad. The next interaction is from a lesson in the teacher-led cluster (low on all autonomy indicators, low quality of scaffolding, and high on dispersion), which contains most of Milou's lessons. During the following interaction (which continues throughout the lesson), the teacher repeats a series of pieces and exercises from previous lessons.

Excerpt 2. Teacher-Student Interaction in Teacher-Led Cluster (Milou)

- T: Let's start with *Twinkle, Twinkle Little Star*.
- S: [Plays *Twinkle*, all correct notes, some slightly out of tune]
- T: Very well. Nice straight bowing. Now the scale of A. With long, long [demonstrates bowing]. Nice up straight.
- S: I'm not sure [...]
- T: [Physically molds student's bowing hand in position] Well you start on the A string, a, a, then with one finger [places student's finger on the string], b, b, then high second finger, c sharp ...
- S: Long or short?
- T: Long long, everything twice long.
[Student plays scale, all correct notes]
- T: Yes, nice. And can you do all the strings without the fingers? E, e, A, a, d, d, g, g, [holds student's hand]
[Student plays on open strings, all notes correct]
- T: Yes. And now again the scale of A.
[Student plays scale of A, all correct notes]
[...]
- T: Menuet 3. [Plays the first half bar]. That one. The start. [Plays first half bar again]
[Student starts playing; teacher stops her after the first bar]

- T: No, just do the beginning. [Plays first half bar]
 [Student plays first half bar]
 T: Hmm, again.
 [Student plays first half bar]
 T: And ... [Teacher plays first half bar, slightly more emphasis on the second note]
 [Student plays half bar, same as before]
 T: Okay, and go on.
 [Student plays whole piece]
 T: Good. Really well done, nice bowing, nice and straight bowing.

During the first part of the interaction, the teacher asks the student to play three basic assignments (a simple piece, a scale, and open strings). The teacher does not explain why the exercises are necessary or ask the student to think for herself or show initiative. After the student executes each assignment (mostly correctly), the teacher responds shortly with “Yes, nice” and then moves on to the next assignment. In terms of scaffolding, the level of the next assignment does not correspond with the student’s level: When the student executes an assignment correctly (playing a scale, thus combining right-hand and left-hand actions), the teacher sometimes responds by giving her an easier assignment (playing the same rhythm on open strings, only right-hand action). Later on in the lesson (the second part of the interaction) we see similar patterns with another piece. Although there is a certain order in first playing a small part of the piece and then playing the whole piece, this sequence of assignments does not seem to build on what the student has and has not yet mastered. More important, the teacher does not explain what is expected or ask for input from the student. The interaction is again being determined almost solely from the side of the teacher. This seems to be a pattern that this teacher and student get more and more stuck in over longer periods of time.

Robin: Falling Back Into Suboptimal (Autonomy) Attractor States

The first illustration is from a lesson in the autonomy-building cluster, which consists of a couple of lessons with high autonomy support by the teacher but also high levels of out-of-synch moments in the autonomy interactions. At the beginning of this lesson, the mother of Robin tells the teacher (without him hearing) that she is concerned about Robin’s motivation: He has told his mother that he wants to quit violin lessons after learning the piece he is currently working on. The mother asks the teacher whether she can help her work on motivation, as we see in the first part of the excerpt.

Excerpt 3. Teacher–Student Interaction in Autonomy-Building Cluster (Robin)
 1.10

Teacher is tuning her violin, Robin picks up his violin out of the case and tries to put the chin rest on.

Mother [in English]: Can you [...] on motivation?

T [in Dutch]: Say that again?

Mother [in English]: Can you help me work on motivation?

T [in Dutch]: Yes. Very well. We'll do that. Does he ...?

Mother [in English]: He thinks he's had enough after Number 17.
And that he wants to quit violin.
[...]

T [in Dutch, walks toward mother]: Do you think that?

Mother [in English]: He says. That then he wants to quit.

T [in Dutch]: Okay, do you ...

Mother [in English]: He says he wants to quit. I don't agree. So we
need to work on motivation.

*Teacher tunes Robin's violin and gives it to
him. He puts it on the floor in front of him.*

T: Robin. What do you want to do today?

S: Hmmm.

T: What do you feel like doing?

[Student remains silent, looks at teacher]

T: You can say it.

S: Song 8.

T: Song 8, great! Song 8, fun. Well, get your
violin, stand up, then we'll play Song 8

[...]

T: I asked you before what do you want to play.
Well, Song 8. Well, now we did. What do you
want to learn today?

S: Hmmm.

[Silence]

T: Do you want to learn a new piece?

S: [Looks at teacher silently]

T: Or do you want to learn the notes, what they
are called?

S: [Looks down]

T: Or do you want to learn something of the
bow?

S: [Looks down]

T: What do you want to learn today? Or do you
want to learn to play together?

[Silence]

S: Hmm. New piece.

T: New piece?

S: [Nods]

T: New piece? Nice! Then we'll do that.

In the second part of the excerpt, we see that the teacher seems to translate Robin's mother's request to "work on motivation" into giving the student a lot of choice in the activities for that lesson (by letting him formulate what he wants to learn and letting him choose a piece to play), thereby supporting the student's autonomy. However, the student does not really respond to this high level of autonomy support: The teacher needs to ask him several times before he answers (which means that their dialogue is out-of-synch in terms of autonomy). This excerpt is relevant because it shows a (brief) attempt by the teacher to break out of the patterns of interactions they have formed as a dyad. As we can see in the next excerpt, however, this attempt is not very long lived, as the dyad falls back into more teacher-directed interaction.

The second illustration is from a lesson that falls into the chronologically last skill-building cluster (in which student engagement levels as well as out-of-synch levels are low but there is a high level of contingent scaffolding). In this specific lesson, the student and teacher spend most time working in depth on a longer piece of music, in which the teacher picks out certain points of improvement and lets the student work on them in small steps. Before the next excerpt the student played the whole piece, during which the teacher made some comments about bow movements and intonation (the student tended to place his fingers slightly back, resulting in some notes being out of tune).

Excerpt 4. Teacher–Student Interaction in Skill-Building Cluster (Robin)

- T: Well done Robin. Now you can play it again, and I will play it together with you. And we always start at this point of the bow [points]. Well, you can take your violin [hands the violin to student] and first play pizzicato the third finger, so we know he is in the correct position, right?
- S: [Plays three notes pizzicato, in tune but very soft]
- T: A bit louder, go on.
- S: [Plays same notes louder]
- T: Well done. And now as loud as you can.
- S: [Plays three notes even louder]
- T: And now you play all notes twice.
- S: [Plays longer fragment, correct and loud]
- T: Very well. There we go together.
- [Student and teacher play whole piece together]

In this second excerpt, we can see the teacher carefully scaffolding the intonation of the first notes of the piece of music they are studying. The goal is broken into small steps, and each next step (playing a longer fragment) is taken only when the student masters the previous steps. However, we also see that the interaction is completely teacher directed. Although the teacher explains why the exercise is important (to make sure the fingers are in the right position), she does not further involve the student by asking questions or providing him with a choice, in contrast with the lesson from the previous cluster.

Thijs: The Emergence of Positive Attractor States

The following lesson is one of the first lessons of this dyad on video. These first four lessons are marked by conflict (high levels of student resistance, out-of-synch, and dispersion combined with low levels of autonomy support). The lesson starts with a fragment in which the teacher tries to persuade the student to sit in the correct posture (on the front edge of the seat in an active position instead of leaning back). There is some struggle as the student does the exact opposite of what the teacher asks (leaning back even more). In the last turn, the teacher explains why the assignment is important and the student eventually cooperates. After some time (the second part of the excerpt), the teacher asks the student to play *Twinkle, Twinkle Little Star* while she accompanies him on the piano. Also in this interaction, the student does not seem inclined to go along with this request (he says “no,” rubs his eyes, sighs). The teacher first tries to persuade him by making the assignment easier (letting the student only play a part of the song), but he gives up altogether.

Excerpt 5. Teacher–Student Interaction in Conflict Cluster (Thijs)

- T: Come sit nicely on your chair. Do what I’m doing [spreads arms].
 S: [Spreads arms]
 T: Well sir, you’re not secretly leaning back on the chair right? [Smiles]
 S: [Smiles]
 T: Come sit on the front of the seat, with only your bottom.
 S: [Looks down, leans back]
 T: [Walks toward student, holds his cello] Come sit on the front of the seat [whistles].
 S: [Smiles, leans back]
 T: Come on.
 S: [Moves even more to the back]
 T: Huh! That’s the wrong way! Come sit on the front of the chair.
 S: No.
 T: Yes! Because otherwise the cello leans against the chair, and the cello will say, ouch that hurts! We don’t want that, remember?
 S: [Moves to front of the chair]
 T: Ah, that looks good.
 [...]
 T: Can play one with “apple pie” [rhythm]?
 S: No.
 T: Man, are you so tired?
 S: [Silence]
 T: I know something. Put your bow on the D string [student puts bow half on D string]. You don’t play one round, and then the next round you play. Then your fingers can relax a bit.
 S: [Takes his bow off the string, rubs his eyes]
 T: Then you put your hand like this, like this [demonstrates].

- S: [Rubs his eyes, looks down]
 T: The first one is mine [starts playing the piano]. Now you can play along.
 S: [Puts bow back on string, leans back, plays two notes [incorrect]]
 T: Or do you need to relax a bit.
 S: [Takes bow of the cello, puts chin on the cello]

Although the student shows active resistance, we see that the teacher remains autonomy supportive. This seems to be an effective strategy over the long term, because after a few lessons the dyad's interactions become more and more characterized by a flow-like state: high-quality scaffolding, high student engagement, and high teacher autonomy support. These types of interactions serve as a positive attractor for this dyad. Even when later on the dyad falls back into more teacher-led interactions, they manage to switch back to flow-like interactions at the end of the time series. The next excerpts are typical of the interactions in the positive attractor state.

In the next excerpt as well as throughout the rest of the lesson we can see how the teacher combines scaffolding the student's skills with supporting the student's autonomy. The student actively voices his opinion about his own performance: "Until here I can still manage well." However, the teacher also prompts him to think critically about the parts that did not go so well (in this case, the problem is that the student plays the long notes too short, thereby playing the wrong rhythm). Instead of telling him this, she asks him what he thinks went wrong and makes some suggestions for improvement (reading the sheet music a bit in advance so he knows when the longer notes are coming).

Excerpt 6. Teacher–Student Interaction in Flow Cluster (Thijs)

[Student plays part of a piece from sheet music. Teacher accompanies him on the piano. Partially correct: Student can play most of the notes but makes mistakes in counting, long notes are played too short.]

- T: Okay, until here for now. I think you still ...
 S: Until here I can still manage well.
 T: Well, I still think you get a bit confused with my piano playing. Am I correct or not?
 S: Hmmm. I don't think it's because of your piano playing.
 T: Okay, why is it do you think? Because I still have to cheat a bit with my notes.
 S: Ehhmm ...
 T: That's weird right?
 S: I think it is because [points at sheet music] I don't remember some of the notes.
 T: Okay, so that's it. Could it be an idea that, because you have the sheet music in front of you, that you apply the trick of reading in advance?
 S: What do you mean with reading in advance?
 T: Do you have to read out loud in the class sometimes?
 S: No.
 T: That's a pity. Because with reading out loud [...] your eyes are already a couple of words in advance while your still talking. [...] But your eyes already see the

next word [...] Well when you're cycling on the street. If you're on the bike you don't look at the ground. [...] You can better look in front of you because then you know when other traffic is coming. [...] So then you can see things coming. That is the same with music notes. Shall we see if we can do that? Let's see if you can already look ahead a bit with your eyes.

T: Four, three, two, one [plays the piano]

[Student plays same piece with teacher accompanying on the piano. Mostly correct notes but starts to speed up more and more toward the end of the fragment.]

T: Okay, so ...

S: But until there I manage. It's the second line that is a bit ...

T: Yes, okay. So start at the second line, how does that start?

S: [Plays the first bars]

T: Oh, okay.

SUMMARY OF FINDINGS

How Do Teacher–Student Interactions in the Three Cases Change Over Longer Periods of Time (18 Months), and How Do Moment-to-Moment Interactions Link to These Long-Term Changes?

In summary, when we look at changes in autonomy and scaffolding separately, several findings stand out. With regard to autonomy, we see that the members of the three dyads become better adapted to each other over time (i.e., they tend to show fewer moments in the coregulation of autonomy when the interaction is out-of-synch). However, the nature of this adaptation is different for each of the three dyads. The students who have in general a lower need for autonomy tend to express less and less autonomy over time, whereas (at least in the case of Milou) the teacher becomes more and more directive. In the last case, we see a reverse pattern, in which the teacher seems to grow more toward the student's higher level of autonomy expression. In relation to a complex dynamic systems perspective, we see some evidence that the general level of student autonomy (in this study assessed by the teacher) might serve as a control parameter for the possible moment-to-moment interactions: Dyads with a low-autonomy student are more prone to developing mainly teacher-directed patterns of interaction, whereas in dyads with a high-autonomy students an interaction style that is more evenly distributed between teacher and student can be expected.

With regard to scaffolding, all three dyads show high within-lesson variability (dispersion) and also high lesson-to-lesson variability, with no decrease or increase in scaffolding quality over time. On first glance, this is not in line with a complex systems perspective of change, as (temporary) spikes in intraindividual variability are considered a hallmark of change (Siegler & Svetina, 2002; van Dijk & van Geert, 2015).

However, keep in mind that we only calculated dispersion for the scaffolding interactions. High unpredictability of scaffolding patterns within lessons fits well with the definition of scaffolding: Because both the level of the teacher and the level of the student change constantly, the interactions move a lot in the state space. In the future, it would be useful to also look at dispersion or variability in the autonomy variables, which may be a better indicator of change in interactions.

In addition, we looked at the profiles of change of the three dyads and how they link to moment-to-moment interactions. The three dyads show distinct change profiles over longer periods of time. In the case of Milou, we see a strong negative attractor state emerging. The teacher and student reinforce each other negatively with regard to autonomy: Instead of building the student's autonomy, the student (who is overall already quite low on autonomy) becomes even less autonomous, while the teacher becomes more directive, and so on. Also, this last stage of change is linked to a lesser quality of scaffolding. When we zoom in on the moment-to-moment interactions, these become, toward the end of the lesson series, characterized by a pattern in which the student and teacher seem to go through the motions of the lesson without the student being challenged to either actively be involved in the lesson or perform at a higher level. In the case of Robin, there is a risk of developing a similar kind of pattern. However, there is an interesting turn of events when the teacher notices a diminished sense of motivation and actively tries to support the student's sense of autonomy by providing more autonomy support. The student does not quite respond to this attempt, perhaps because this mode of interaction is too far out of the dyad's common pattern. As a result, the dyad quickly falls back into interactions that are focused more on careful skill acquisition than on scaffolding the student's sense of autonomy.

The case of Thijs, in contrast, shows the emergence of more positive attractor states over time. The dyad starts out with interactions that are characterized by conflict and student (explicit and implicit) resistance. However, as we concluded from the micro-level analyses, the teacher keeps responding in an autonomy-supportive way. Over the long term, this helps the dyad move toward a much more positive flow state in which high-quality scaffolding, positive mutual reinforcement of student autonomy expression, and teacher autonomy support come together. This is illustrated by their moment-to-moment interactions in these flow lessons. When the student is actively let to think about how he can improve his performance, a sense of ownership is created. In turn, this leads to a high quality of scaffolding that is in tune with the student's needs.

DISCUSSION

Scaffolding and Autonomy as Agency

Scaffolding and autonomy are connected theoretically through the notion of agency, both of the student and of the teacher (Meyer & Turner, 2002; Steenbeek

& Van Geert, 2013). Our results indicate that the ways in which autonomy and scaffolding are related can be different for different teacher–student dyads. One possibility is that teacher–student interactions are primarily focused either on building the student’s autonomy or on building the student’s skills through step-by-step, teacher-led scaffolding. However, scaffolding skills and scaffolding autonomy can also be intrinsically intertwined when teacher and student develop the pattern of triggering the student to think about ways to improve his or her performance. In this way, fostering the student’s autonomy can lead to the student better understanding his or her own learning process and thereby to deeper and more lasting forms of learning (McPherson et al., 2016).

Autonomy in the Context of Individual Music Lessons

The analysis of teacher–student interactions in individual music lessons is a theme that is receiving more and more attention in the music education literature. The picture that arises from these analyses is that in the classical structure of the individual music lesson, interactions seem to be heavily teacher directed, with little room for student initiative and autonomy. On top of that general finding, critics of the Suzuki method fear that this method puts an even larger constraint on both teacher and student autonomy, with the risk of teacher and student being slaves of the method (Juntunen & Westerlund, 2011; Regelski, 2002).

Our results paint a more nuanced picture. First, there is indeed the risk that with students who are already low in autonomy, more teacher-directed patterns of interaction will develop. However, we also saw an example of a dyad that developed toward more positive states. A second issue that stands out is the large variety of learning trajectories (see also Kupers, van Dijk, & van Geert, 2015) that are possible within a sample of teachers all trained in using the Suzuki method. Although the method is probably still a constraint in terms of which interactions are more or less likely to occur, it is clear that teachers still have (and make use of) the freedom to be flexible in adapting their instruction. This negotiation between functioning within the structure of a teaching method while at the same time being flexible in responding to the student’s needs is what Sawyer (2004, 2011) called “disciplined improvisation.” This disciplined improvisation is the core of the practice of high-level, experienced teachers. From a complex dynamic systems point of view, this balance between real-time emergence and top-down constraint is characteristic of healthy, optimally functioning dynamical systems (resulting in so-called pink noise; Den Hartigh, Cox, Gernigon, Van Yperen, & van Geert, 2015; Van Orden, Holden, & Turvey, 2003).

Implications for Practice and Future Research

Our results show that teachers and students can develop more optimal patterns of learning and teaching as they get to know each other over time but also that

suboptimal patterns can develop that can be hard to break out of. A first step in improving practice is that teachers *become more aware* of how suboptimal patterns (for instance, ways of interacting that neither foster the development of autonomy nor result in optimal forms of learning) can become stronger over time so that they can find ways to break out of these patterns. We also see, however, that sometimes this awareness and the teacher's efforts to make change happen do not always produce the desired effect. In terms of a complex dynamic systems approach, this could be explained in terms of the timing and magnitude of change: A system is less susceptible to change when strong attractor states have already been formed. Also, when the behavior of the teacher (for instance a sudden increased level of autonomy support) is so far beyond the zone of proximal development of the regular teacher–student interaction, the system can quickly fall back into previously formed states.

In this sense, our results and recommendations are very much in line with the work of Creech (2012), who stated that a teacher's general teaching style (which she found to be at times quite directive) can function as a constraint on moment-to-moment interactions. Following the first step (teachers becoming more aware of the patterns that develop in interaction with their pupils), a second important recommendation is therefore that teachers *remain flexible* to improvise in their teaching and respond to students' needs. Their previous experience, their developed teaching style, and the method that they may use can then serve as a toolkit with a large repertoire of different strategies that can be used to solve different problems they can encounter in their lessons rather than as a set of fixed rules that apply to every student in every case.

With regard to the implementation of educational interventions in general, this finding stresses the importance of diagnosing the current state of affairs (the current level of the teacher, students, their needs, etc.) and the processes leading up to that state before starting an intervention and expecting it to work immediately.

Most (quantitative) studies from a complex dynamic systems point of view focus on dyadic interactions, for instance, interactions between mother and child (Lougheed, Kovak, & Hollenstein, 2015; van Dijk, Hunnius, & van Geert, 2009) or between one teacher and a student (Steenbeek et al., 2012). Also, this study focused on one-to-one interactions in music lessons. These contexts are some of the main contexts in which children learn and develop. However, children of course also learn in everyday group contexts, such as classrooms, and in the case of music, ensembles or group lessons. On the one hand, including group contexts in a microgenetic design can make a study methodologically more difficult. On the other hand, group dynamics between the teacher and multiple students could provide us with interesting new perspectives on how patterns of learning and teaching emerge, which makes this an interesting direction for future research.

The aim of this study was to analyze change in teaching and learning from the theoretical framework of a complex dynamic systems approach. In order to study the link between moment-to-moment change within a lesson and change over longer periods of time we chose to combine quantitative cluster analyses and the detection of key moments on the basis of those clusters that served as qualitative illustrations. Analyzing the data both quantitatively and qualitatively from a complex dynamic systems framework offers a new perspective on the meaning and mechanisms of change over time. On the one hand, quantitative analyses of large amounts of rich (video) data allow us to detect overall patterns of change systematically that would otherwise go unnoticed (Martin & Sherin, 2013). On the other hand, zooming in on specific moments in teacher–student interactions provides a more in-depth image of what happens from moment to moment and thereby of key moments in the short-term interactions that drive long-term change. In terms of the practical use of this study, our results show the importance of teachers being aware of the patterns of learning and teaching that develop over time in their lessons and being able to remain flexible within the structure of the teaching method and their own personal teaching style.

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